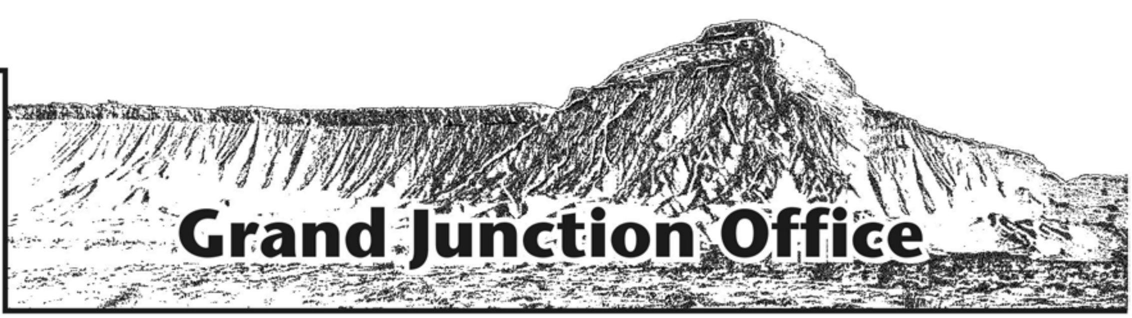
Hanford Tank Farms Vadose Zone Monitoring Project

Baseline Monitoring Plan

February 2003

U.S. Department of Energy



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February 2003

Prepared for
U.S. Department of Energy
Grand Junction Office
Grand Junction, Colorado

Prepared by
S.M. Stoller Corp.
Grand Junction Office
Grand Junction, Colorado

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Prepared by:

Feb 24, 2003

Richard G. McCain, Technical Lead
S.M. Stoller Corp., Hanford

Date

Approved by:

2/28/03

Michael Butherus, Program Manager
S.M. Stoller Corp., Grand Junction

Date

W.D. Steele

2/25/03

W.D. Steele, Project Manager
S.M. Stoller Corp., Grand Junction

Date

3/4/03

Robert Yasek, Project Manager
U.S. Department of Energy
Office of River Protection

Date

03.04.03

John Silko, Program Manager/COR/TOM
U.S. Department of Energy
Richland Operations Office

Date

1.0 Introduction

The U.S. Department of Energy (DOE) Office of River Protection (DOE-ORP) has requested that the DOE Grand Junction Office (DOE-GJO) develop and implement a monitoring system to detect and track changes in subsurface profiles of gamma-emitting radionuclides in steel-cased boreholes. This system will be used in existing vadose zone boreholes around and near the Hanford single-shell tanks to detect radionuclide contaminant migration resulting from tank leaks and/or other contamination events related to tank farms operations. In addition, monitoring results that do not exhibit change over time will be useful in demonstrating the immobility of radionuclides under present subsurface conditions.

The Hanford Tank Farms Vadose Zone Monitoring Project is an extension of the recently completed single-shell tank vadose zone baseline characterization project. As operating contractor for the DOE Grand Junction Office, S.M. Stoller Corp. (Stoller) is responsible for performing this task.

The purpose of this document is to define the tasks and organizational requirements associated with routine monitoring operations in the single-shell tank farms. Specific tasks included in this work scope include:

- Evaluation of existing data and development of a database of existing boreholes associated with the single-shell tanks. This database will include information derived from the baseline characterization effort, historical gross gamma data, and tank conditions relevant to monitoring.

- Selection and prioritization of individual borehole intervals to be logged

- Scheduling of monitoring operations

- Monitoring data acquisition

- Data evaluation

- Reporting and investigation of anomalies

- Routine reporting

The scope of the Hanford Tank Farms Vadose Zone Monitoring Project includes routine monitoring operations in approximately 769 existing cased boreholes associated with the twelve single-shell tank farms on the DOE Hanford Site. Within work scope modifications and configuration control processes, Stoller shall provide limited support for special request, project-related work scope, commensurate with ongoing borehole monitoring.

2.0 Background

The 200 Area plateau is the site of chemical processing plants used to separate and recover plutonium and uranium from irradiated reactor fuel elements. Approximately 53 million gallons of highly radioactive waste are currently stored in 177 underground tanks with capacities ranging from 55,000 to more than 1 million gallons. One hundred forty-nine of these tanks are of single-shell design, consisting of a concrete shell with a steel liner. Sixty-seven single-shell tanks are currently designated as "assumed leakers," with an aggregate leak volume of approximately 1 million gallons.

Tank leaks have historically been detected with a combination of external and internal monitoring. Internal monitoring includes liquid-level or surface measurements. External monitoring was performed with gross gamma logging measurements in boreholes surrounding the single-shell tanks. According to Scott (1993), 26 tanks have been classified as potential leakers on the basis of external leak detection.

From the early 1970s to 1994, external monitoring was performed in boreholes surrounding the single-shell tanks using gross gamma detector systems based on sodium iodide (NaI) scintillation detectors or Geiger-Mueller (GM) tubes. No effort was made to segregate counts by energy level, and the log results consist of a plot of total gamma activity as a function of depth. From 1975 to 1994, data are available in electronic format. Gross gamma logging was discontinued in 1994. Although there were a number of technical deficiencies in the gross gamma logging program, it produced a very large dataset that provides a historical record of changes in the vadose zone over time. A qualitative means of evaluating these historical gross gamma logs recently has been developed by Randall and Price (1999c) to evaluate historical movement of gamma-emitting contaminants through the vadose zone in SX Tank Farm. The method has also been applied to historical data from S, BY, TY, BX, T, and B Tank Farms (Randall and Price 1998, 1999a, 1999b; Myers et al. 1999; Randall et al. 2000a, 2000b), with plans for additional tank farm evaluations in the future. This approach is useful to identify borehole intervals where movement of contaminants through the vadose zone is indicated.

Between 1995 and 2000, DOE-GJO conducted a baseline characterization program in the single-shell tank monitoring boreholes using a high-resolution spectral gamma logging system (SGLS). This work scope was primarily conducted for DOE-RL and eventually closed out under DOE-ORP upon the federal legislation identifying two reporting DOE offices at the Hanford Site. DOE-ORP activities officially began in October 1998 and currently continue. The baseline characterization consisted of at least one log run in each borehole, supplemented by limited repeat logging. In addition, a high rate logging system (HRLS) was developed and deployed to investigate regions where the gamma flux was too intense for the SGLS. The purpose of this characterization effort was to acquire a technically defensible baseline of the distribution and concentrations of individual gamma-emitting radioisotopes within the vadose zone around the single-shell tanks.

Results of the baseline characterization are documented in Tank Summary Data Reports for individual tanks. For each tank farm, the baseline is summarized in Tank Farm Reports (DOE 1996, 1997a, 1997b, 1997c, 1997d, 1998a, 1998b, 1998c, 1998d, 1999a, 1999b, and 2000m). An addendum was prepared for each Tank Farm Report to incorporate improvements in interpretation and information gained during the course of the project (DOE 2000a, 2000b, 2000c, 2000d, 2000e, 2000f, 2000g, 2000h, 2000i, 2000j, 2000k, and 2000l). The baseline data provide an indication of the nature and extent of subsurface contamination and serve as a reference against which future measurements can be compared for assessing the stability of subsurface contaminants.

Although the SGLS and HRLS provide high-quality data, the complexity of the equipment, slow logging rate, and analysis time required to obtain useful log data preclude their routine use for monitoring purposes. However, evaluation of the baseline data allows specific borehole intervals to be identified for monitoring purposes. Because radionuclide identity and concentration are known from the baseline data, it is only necessary to detect changes between successive log runs. Long-term stability of contaminants in the vadose zone can be demonstrated by showing that changes between successive log runs are consistent with the radioactive decay process.

A faster logging system known as the Radionuclide Assessment System (RAS) has been designed for rapid screening and routine monitoring. This system utilizes three different sizes of thallium-activated sodium iodide (NaI[Tl]) detectors to measure gamma activity over a wide range. DOE-GJO began conducting routine monitoring in selected intervals of existing boreholes adjacent to the single-shell tanks during the latter half of fiscal year 2001. Operation of the RAS is currently performed by tank farm HAMTC operators. Stoller provides the day-to-day management of the monitoring project, which includes setup and oversight of field logging operations, and analysis, interpretation, and report submittal of the monitoring data. In addition, it is anticipated that special investigative logging will be required using the SGLS and HRLS to investigate anomalies identified in the RAS data.

3.0 Purpose and Scope

The purpose of the Hanford Tank Farms Vadose Zone Monitoring Project is to periodically monitor vadose zone gamma activity in selected borehole intervals within existing monitoring boreholes adjacent to single-shell tanks. There are 769 boreholes associated with 149 tanks, which are organized into twelve tank farms. For readers not familiar with the Hanford Tank Farms borehole numbering scheme, Appendix A is a diagram that shows how to identify the location of a borehole from its identification number. Borehole monitoring frequency will be determined on a case-by-case basis, taking into account existing contamination levels, plume behavior, tank characteristics, and tank farms operational requirements. Each borehole is expected to be logged at least once during a 5-year period.

Data from each borehole will be evaluated to assess the possibility of contaminant migration, as indicated by changes in activity and/or shifts in plume boundaries over time. Routine monitoring will be based on the RAS. However, it is anticipated that additional characterization using the SGLS or HRLS may be required to investigate anomalies.

4.0 Organization and Responsibility

This section defines the organizational roles and responsibilities for the Hanford Tank Farms Vadose Zone Monitoring Project.

4.1 DOE-ORP

DOE-ORP, through its contractor, CH2M Hill Group (CHG), is responsible for management and operations of Hanford tank farms and associated facilities. DOE-ORP approves the work scope for monitoring and provides sufficient and timely funding to the DOE Idaho Office (DOE-ID) for assignment to the Stoller contract. DOE-ORP also provides direction and funding to Hanford Site Contractors as necessary to support tank farm monitoring.

If the results of tank farm monitoring data indicate changes from baseline may have occurred, DOE-ORP may direct the Hanford tank farm contractor to perform a Tank Leak Assessment. DOE-ORP may also designate specific boreholes for monitoring or additional logging with the SGLS, HRLS, or neutron moisture logging system.

4.2 DOE-RL

DOE-RL provides a program manager, task order manager, and contracting officer's representative for the Hanford Tank Farms Vadose Zone Monitoring Project.

4.3 DOE-GJO

DOE-GJO is responsible for geophysical logging activities. DOE-ORP provides funding to DOE-ID on the basis of approved scope, schedule, and cost baselines. DOE-ID authorizes DOE-GJO and its contractor, Stoller, to perform the approved work scope and provides appropriate direction to Stoller to initiate approved tasks consistent with assigned funding.

DOE-GJO will also review and approve administrative plans and procedures prepared by Stoller to ensure that they meet the requirements of the specific work scope, are consistent with DOE-GJO policy and the quality assurance (QA) program, ES&H program, project control programs, and are of adequate technical quality.

4.4 Stoller

As the GJO contractor, Stoller, through its offices in Grand Junction, Colorado, and Richland, Washington, is responsible for project management, planning, cost account management, equipment maintenance and calibration, technical oversight of monitoring operations, data management, data analysis and plotting, report preparation, and technical support to DOE-ORP.

4.4.1 Hanford Office Project Manager

The project manager is responsible for managing project activities and reporting project status and changes to the program manager and the DOE project managers. The project manager directs project activities within authorized funding and approved scope and schedule, and is responsible for cost and schedule control. The project manager reviews and approves all project plans, procedures, reports, and deliverables.

4.4.2 Technical Lead

The technical lead is responsible for the overall technical direction of the project, which includes review and approval of technical documents, including plans, procedures, and special investigation reports.

4.4.3 Lead Data Analyst

The lead data analyst is responsible for routine data analysis and plotting. The lead data analyst evaluates verification measurements and field spectra to ensure detectors are functioning properly, prepares data analysis summaries and plots, performs special investigations to investigate anomalies in RAS data, prepares routine monitoring reports and special investigation reports, and participates in the tank leak assessment process. The lead data analyst also maintains the tank farms monitoring database.

4.4.4 Hanford Project Coordinator

The project coordinator is responsible for the coordination and direction of monitoring activities. The project coordinator works with the monitoring supervisor and field geophysicist to schedule field activities and supports the project manager in budgeting, tracking, and reporting of project activities.

4.4.5 Field Geophysicist

The field geophysicist is responsible for the day-to-day technical supervision and oversight of RAS monitoring activities. The field geophysicist is also responsible for transporting monitoring data files to the office.

4.4.6 Records Coordinator

The records coordinator is responsible for maintaining project files, transfer of field data onto the network computer on a regular basis, and archiving of field data.

4.5 CH2M Hill Group

As the Hanford Site contractor responsible for tank farms, CH2M Hill Group (CHG) is responsible for operating the RAS and for providing tank farms access and support services, including operator and radiological technician support and borehole support services, as required for monitoring activities at the tank farms. CHG will use existing training courses and facilities, as needed, to meet entrance and operating requirements for the tank farms and integrate Stoller personnel into the Access Control Entry System (ACES).

4.5.1 Tank Farms Operations

The Tank Farms Operations Group within CHG is responsible for operating the RAS and for providing tank farms access and support services. The CHG monitoring supervisor will work with the project coordinator and field geophysicist to schedule monitoring operations.

4.5.2 Tank Farms Vadose Zone Project

The Tank Farms Vadose Zone Project within CHG is responsible for integration of the monitoring data into the existing vadose zone conceptual model. The Vadose Zone Group may designate specific boreholes for monitoring or additional logging with the SGLS, HRLS, or neutron moisture logging system.

4.5.3 Data Evaluation (Tank Farms Surveillance)

The Tank Farms Data Evaluation Group within CHG primarily is responsible for evaluation of in-tank monitoring data. The Tank Farms Data Evaluation Group is responsible for conducting the Tank Leak Assessment Process. The tank farms data evaluation group may also designate specific boreholes for monitoring or additional logging with the SGLS, HRLS, or neutron moisture logging system.

4.6 Key Personnel

Key personnel involved in the Hanford Tank Farms Vadose Zone Monitoring Project are listed in Table 4-1.

Table 4-1. Key Personnel for the Hanford Geophysical Logging Project

Title	Name	Telephone Number
DOE-ORP		
Project Manager	Rob Yasek	(509) 372-1270
DOE-RL		
Program Manager/COR/TOM	John Silko	(509) 373-9876
Stoller		
Program Manager	Mike Butherus	(970) 248-6332
Project Manager	Doug Steele	(970) 248-6703
Technical Lead (Hanford)	Rick McCain	(509) 376-6435
Technical Lead (GJO)	Carl Koizumi	(970) 248-7797
Lead Data Analyst	Paul Henwood	(509) 376-6429
Project Coordinator	Steve Kos	(509) 376-6432 (office) (509) 539-9497 (cellular)
Field Geophysicist	Alan Pearson	(509) 376-6440 (office) (509) 531-1246 (cellular)
Records Coordinator	Rachel Paxton	(509) 376-6437
Office Administrator	Jill Meinecke	(509) 376-6454
CH2M Hill Hanford Group (CHG)		
Tank Farms Operations	Doug Larsen	(509) 373-5995
Vadose Zone Group	Tony Knepp	(509) 372-9514
Data Evaluation Group	Kent Hodgson	(509) 373-3513

5.0 Monitoring Database

A database of existing boreholes has been developed to facilitate selection and prioritization of borehole monitoring intervals. A review of available data collected as part of the vadose zone baseline characterization effort provides information necessary to identify specific borehole intervals for future monitoring efforts. Primary criteria for monitoring include:

- Intersection of an existing identified contaminant plume, particularly one in which recent contaminant movement is known or suspected.
- Proximity to a known plume, particularly where the plume is known to be moving.
- Proximity to a tank containing a relatively large volume of drainable liquid.
- Proximity to a tank designated as an "Assumed Leaker," particularly where the leak volume is relatively large.

These criteria can be classified as either plume-related or tank-related. Plume-related factors must be evaluated on a borehole-by-borehole basis while tank-related factors equally apply to all boreholes in the vicinity of a tank. Three priority factors are defined; one based on borehole and plume characteristics, another based on proximity to a tank suspected of leaking, and a third related to the volume of drainable liquid currently stored in the tank. The tank factors are based on data reported in Hanlon (2001). These factors are multiplied by weighting factors to arrive at an overall priority score, by which the order and frequency of monitoring are determined. Details of the prioritization and scoring process are discussed in Appendix A.

It is expected that the database will be continually updated and individual borehole priority scores will change over time as tank data change and as monitoring data are collected and evaluated. In addition, tank farms operational considerations, leak investigations, or other factors related may override borehole priorities derived from the database.

6.0 Selection of Borehole Intervals

Selection of borehole intervals to be monitored will be based on the priority score discussed above. From time to time, tank farms operational considerations may require monitoring of select boreholes. For example, borehole monitoring may be required to support tank farm retrieval operations or interim stabilization efforts, or to provide supporting data for investigation of anomalies relevant to the in-tank monitoring data. Baseline spectral data and historical gross gamma data will be evaluated to select specific depth intervals for monitoring. In general, borehole intervals will be selected to "bracket" zones of known contamination or zones in which contamination may be expected to occur in the future. In the case of a borehole (with no pre-existing contamination) located adjacent to a tank suspected of having leaked in the past or currently containing a relatively large volume of drainable liquid, the monitoring interval may extend from an elevation above the operating level of the tank to the total depth of the borehole.

Special monitoring requests by DOE-ORP or CHG tank farms organizations are expected. Any request by DOE-ORP or CHG to monitor borehole intervals other than those identified by the database will be documented by a brief memorandum including the name and organization of the individual requesting the monitoring, a brief justification for monitoring, and anticipated contaminant levels.

7.0 Scheduling Monitoring Operations

A three-month schedule of borehole intervals to be monitored will be developed and periodically updated. It is anticipated that monthly meetings will be held to discuss borehole selection, plan logging activities, and resolve any technical or administrative issues related to monitoring. In general, monitoring operations will be scheduled to minimize detector changes and moves between tank farms. In some cases, tank farms operational considerations and access requirements may affect the order in which boreholes are monitored. Because operators for the RAS are not solely dedicated for this program, operator training and availability, and vehicle or system maintenance requirements will also affect monitoring operations. The schedule will also be modified as necessary to support priority monitoring operations as directed by DOE-ORP.

8.0 Data Acquisition

The detailed RAS data acquisition process is described in the RAS operating procedure (DOE 2003c). The general order of operation in the field will be as follows:

1. Assemble detector and telemetry section to cable.

2. Insert sonde in field verifier. Adjust gain to center the ^{40}K peak (1460.8 kilo-electron volts [keV]) in the correct window and collect a verification spectrum, using the appropriate count time for the detector.

3. Set up the sonde at the borehole and perform the zero depth adjustment.

4. Lower the sonde to the monitoring interval and stop at the depth specified for gain adjustment.

5. Adjust the gain to center the correct peak in the appropriate window. Where contamination is present, the peak used for gain adjustment will generally be a prominent peak associated with the contamination, such as the ^{137}Cs peak at 662 keV. If no contamination is present, the ^{40}K peak at 1460.8 keV should be used for gain adjustment. When the gain adjustment is completed, collect a pre-run spectrum using the appropriate count time for the detector.

6. Log the borehole interval at the appropriate logging speed.

7. Return to the depth where gain adjustment was performed and collect a post-run spectrum, without gain adjustment, using the appropriate count time for the detector.

8. Save the data to the zip disk.

9. Move to the next borehole scheduled for monitoring and repeat steps 4 - 8. If a different detector is required, repeat steps 1 - 8.

At the close of each day, the zip disk and log data sheets will be transported by the field geophysicist to the office for transfer to the computer network. If there is sufficient storage capability remaining, the zip disk can be returned to the field for additional data collection. If not, the zip disk will be archived.

9.0 Data Evaluation

Although individual spectra will be collected and recorded by the RAS, routine data evaluation will not involve spectral analysis. Specific contaminants and activity levels are known from the baseline characterization data. The primary goal of RAS data evaluation will be to detect changes between successive runs that may indicate contaminant migration.

Evaluation of RAS data will be performed in accordance with the project data analysis manual (DOE 2003a). Potential contaminant migration is anticipated to be expressed in one of two ways:

- Change in activity at a specific depth that appears to be significant.
- Increases in thickness of the contaminated interval or vertical displacement of the contaminated interval.

The RAS spectra have been divided into eight contiguous windows that represent specific radionuclides of interest. Table 9-1 presents the window definitions for each detector.

Table 9-1. RAS Window Definitions

Window		Energy Range (keV)	MCA Channel Settings	
			Large (L)	**Medium (M) and Small (S)**
Lithology	1	0 – 570	0 – 50	0 – 51
Cesium	2	570 – 740	51 – 64	52 – 66
Midrange	3	740 – 940	65 – 82	67 – 83
Protactinium	4	940 – 1060	83 – 92	84 – 93
Cobalt	5	1060 – 1390	93 – 121	94 – 121
Potassium	6	1390 – 1600	122 – 139	122 – 138
Uranium	7	1600 – 2400	140 – 209	139 – 202
Thorium	8	2400 – 2800	210 – 255	203 – 255

The RAS software generates a data file that includes the counts for each window as a function of depth, as well as, other parameters including dead time and the filename of the associated spectrum. This file will be imported into EXCEL and plotted. Corrections will be made for radioactive decay and data from successive runs will be compared.

The mathematical method used to identify significant changes on a point-by-point basis is discussed in Appendix B. Detection of anomalies in the RAS data are usually based on graphical evaluation of multiple data points. This is normal because normal statistical fluctuations associated with radioactivity can often result in individual data points that appear to be anomalous. Therefore, the presence of a significant change in multiple contiguous depths is an indication of an anomaly. Accordingly, data evaluation will primarily be based on comparison of log data plots between successive log runs.

10.0 Reporting and Investigation of Anomalies

Anomalies in the RAS data may be associated with detector drift, equipment or procedural problems, movement of an existing contaminant plume, or detection of a previously unknown or new contaminant plume. Data acquisition and evaluation procedures have been structured to support quick identification and correction of anomalies resulting from detector drift, equipment, or procedural problems. In extreme cases where the data are questionable, the analyst may request that the borehole be relogged.

Continued movement of an existing contaminant plume is anticipated to be the most common type of anomaly encountered in the RAS data. As more data become available from successive log runs, it will be possible to estimate whether the contaminant migration rate is constant, increasing, or decreasing over time. Once a migration rate is established, continued movement consistent with the previously established rate would not necessarily be considered an anomaly.

Any anomalies indicating changes in subsurface contaminant conditions will be reported to DOE-ORP and to representatives of the Tank Farms Vadose Zone Project and the Data Evaluation Group. Notification will be made immediately after preliminary data analyses have been completed to ensure that the anomaly is not caused by equipment or procedural problems. In addition, notification will be made to the Geophysics Program Manager. After initial notification, Stoller will continue to investigate the anomaly with the use of historical data, the baseline characterization data, logs from nearby boreholes, and tank farms operational data. Additional RAS, SGLS, or HRLS logging may be performed to gather additional data as appropriate. Results of the investigation may be issued as a memorandum, letter report, or special report, depending on the level of complexity involved. Stoller will support as directed any follow-on investigations conducted by the Tank Farms Data Evaluation Group or the Tank Farms Vadose Zone Project. The goal will be to provide a credible and defensible explanation for all anomalies observed in the monitoring data.

11.0 Reports

11.1 Routine Reports

Field operations reports will be issued at the close of each day RAS operations are conducted.

Other routine reports will be issued on a weekly basis as described in the Project Management Plan (DOE 2003b). These reports will summarize the results of logging performed during the reporting period, provide the status of any on-going special investigations, and provide an updated listing of borehole intervals where logging is planned in the coming months. Quarterly and annual reports will also be prepared to summarize results. The annual reports will be subject to review and approval by DOE-ORP and DOE-RL.

11.2 Special Reports

Special reports will be prepared and presented based on response to unique or unusual tank farms interests or activities.

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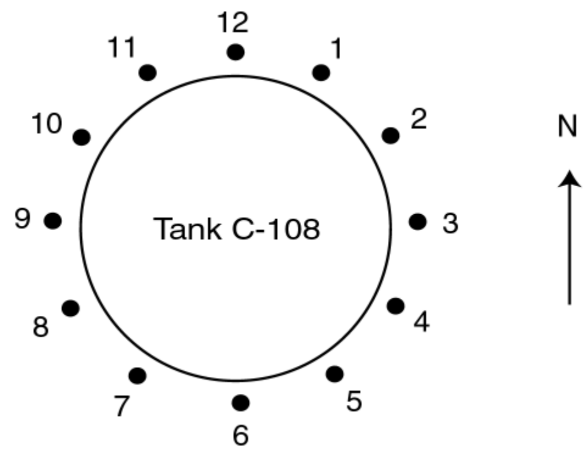
Appendix A
Legend for Identification of Hanford Tank Farm Boreholes and Monitoring Wells

Tank Farm Numbering Scheme

A Farm	10
AX Farm	11
B Farm	20
BX Farm	21
BY Farm	22
C Farm	30
S Farm	40
SX Farm	41
T Farm	50
TX Farm	51
TY Farm	52
U Farm	60

Tank Farm Borehole Numbering Scheme



Boreholes are identified by numbers using the format FF-TT-PP, where "FF" = tank farm, "TT" = tank, and "PP" = the position around the tank in a time-clock numeral from 1 to 12 (12 = north). For example, borehole 30-08-02 is in the C Tank Farm, around tank C-108, and at approximately the 2 o'clock position.

Appendix B
Identification and Evaluation of Borehole Intervals for Future Monitoring

Identification and Evaluation of Borehole Intervals for Future Monitoring

A review of available data collected as part of the vadose zone baseline characterization effort provides information necessary to identify specific borehole intervals for future monitoring efforts. Primary criteria for monitoring include:

- Intersection of an existing contaminant plume, particularly one in which recent contaminant movement is known or suspected.
- Proximity to a known plume, particularly where the plume is known to be moving.
- Proximity to a tank containing a relatively large volume of drainable liquid.
- Proximity to a tank designated as an "Assumed Leaker," particularly where the leak volume is relatively large.

These criteria can be classified as either plume-related or tank-related. Plume-related factors must be evaluated on a borehole-by-borehole basis while tank-related factors apply equally to all boreholes in the vicinity of that tank.

Borehole (Plume) Priority Factors

Situation	**F1**
No evidence of man-made contamination	0
Possible plume (generally low-level, ambiguous)	0.5
No plume, or ambiguous, near borehole with movement	0.75
Definite plume	1
Definite plume, near borehole with movement	1.5
Definite plume, indications of continued movement	2

$0 < F1 < 2$

Tank Priority Factors

Association With a Tank Containing Drainable Liquid:

$F2 = K_{PLD} * V_{DL} / K_{DL}$

Where K_{PLD} = constant depending on primary leak detection method
V_{DL} = volume drainable liquid, Kgal
K_{DL} = constant for volume, Kgal

	LOW	ENRAF	FIC	MT	none
K_{PLD}	0.25	0.5	0.75	0.75	1

$0 < F2 < 15.05$ $(K_{DL} = 10)$ 95% < 5

Association With a Tank Designated as a Leaker:

$F3 = V_{leak} / K_{leak}$

Where V_{leak} = mean leak volume, Kgal
K_{leak} = constant for leak volume, Kgal

$0 < F3 < 28.7$ $(K_{leak} = 5)$ 95% < 5

Total Priority Score:

$PS = 3 \{F_i * W_i\}$

Where W_i are "weights" for each factor discussed above

Choose W_i such that max PS approximately 100, with 50% from F1 (plume), 30% from F2 (drainable liquid) and 20% from F3 (leak volume). Use the 95% values for F2 and F3.

$W_1 = 50/2 = 25$

$W_2 = 30/5 = 6$

$W_3 = 20/5 = 4$

Tank Score = $W_2F_2 + W_3F_3$

Recommended Logging Frequency

Situation	**Frequency**
Plume with indications of movement (F1 = 2)	semi-annual (0.5)
Definite plume (F1 = 1 or 1.5)	annual (1)
Priority score > 75	annual (1)
Default	5 years (5)

Appendix C
Minimum Detectable Difference in Counts

Determination of Minimum Detectable Difference in Counts

Reference: Knoll, Glenn K., 2000. *Radiation Detection and Measurement*, 3rd edition, John Wiley and Sons, New York, pp. 94-96.

N_1 and N_2 are two individual measurements acquired at different times. Both are taken to be estimates of the mean value of a Gaussian distribution at the time of measurement. The estimate for the standard deviation is equivalent to the square root of the counts.

$$\sigma = \sqrt{N}$$

The count rates, R_1 and R_2, are determined by dividing the counts by the live time. The count rate also represents a Gaussian distribution, since R = N/T. The estimate of the standard deviation for the count rate is:

$$\sigma = \frac{\sqrt{N}}{T} = \frac{\sqrt{RT}}{T} = \sqrt{\frac{R}{T}}$$

The difference in count rates between the measurements should also be Gaussian.

If there is no actual difference in the two counts, then the true mean values for R_1 and R_2 are the same and:

$$\sigma_{\Delta R} = \sqrt{\sigma_{R_1}^2 + \sigma_{R_2}^2}$$

We need to define a critical level, L_1, so that the probability of false positives is minimal. For a one-tailed normal distribution, there is a 95% probability that a random sample of R_2 will lie below the mean + 1.645 σ

Also, $\sigma_{R1} \approx \sigma_{R2}$, so that: $\sigma_{\Delta R} = \sqrt{\sigma_{R_2}^2 + \sigma_{R_1}^2} = \sqrt{2} \times \sigma_{R_1}$

Therefore: $L_1 = R_1 + 1.645 \times \sqrt{2} \times \sigma_{R_1} = R_1 + 2.326 \times \sigma_{R_1}$

In the case where a real difference in activity exists, the true mean value for ΔR is >0, and we need to define the minimum value of R_2 for which the probability of false negatives is minimal. If $R_2 = L_1$, the false negative rate will be 50 %, because a Gaussian distribution is symmetric about its mean. To ensure that 95 % of the values in the R_2 distribution lie above L_1, we define L_2 so that:

$$L_2 = L_1 + 1.645 \times \sigma_{\Delta R}$$

also, $\sigma_{R2} \geq \sigma_{R1}$, so that: $\sigma_{\Delta R} = \sqrt{\sigma_{R_2}^2 + \sigma_{R_2}^2} \leq \sqrt{2} \times \sigma_{R_2}$

$$L_2 = R_1 + 2.326 \times \sigma_R + 2.326 \times \sigma_{R_2}$$

L_2 defines the level above which there is a 95% probability that the count rates are different.

For radiation measurements, $\sigma_N \approx \sqrt{N}$: $\sigma_R = \sqrt{\frac{R}{T}}$

$$L_1 = R_1 + 2.326 \times \sqrt{\frac{R_1}{T_1}}$$

$R_2 \leq L_1 \Rightarrow$ no significant difference (95%)

$$L_2 = R_1 + 2.326 \times \sqrt{\frac{R_1}{T_1}} + 2.326 \times \sqrt{\frac{R_2}{T_2}}$$

$R_2 \geq L_2 \Rightarrow$ significant difference (95%)